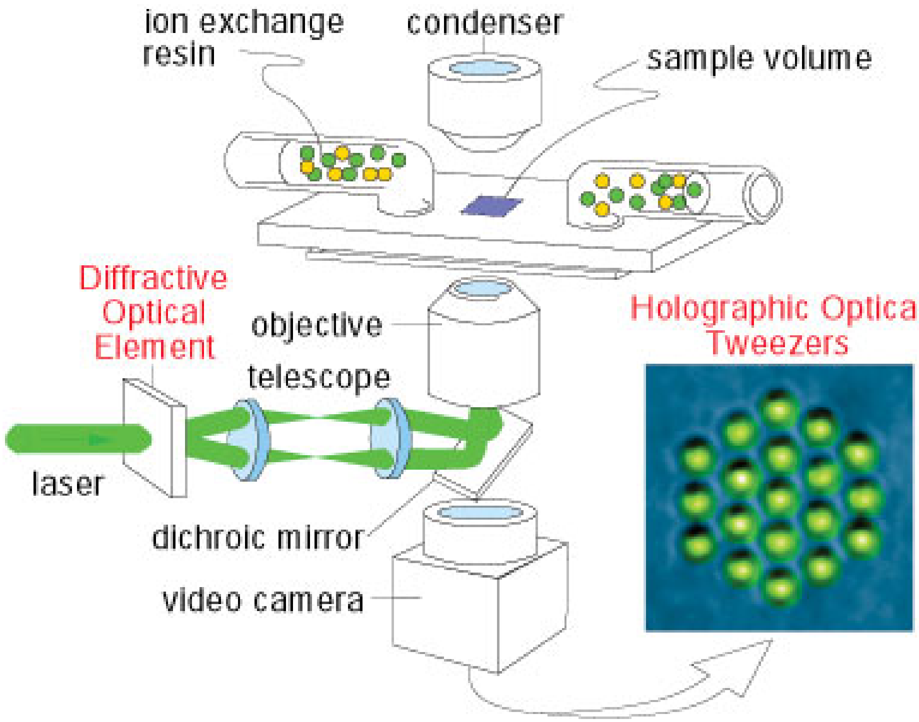
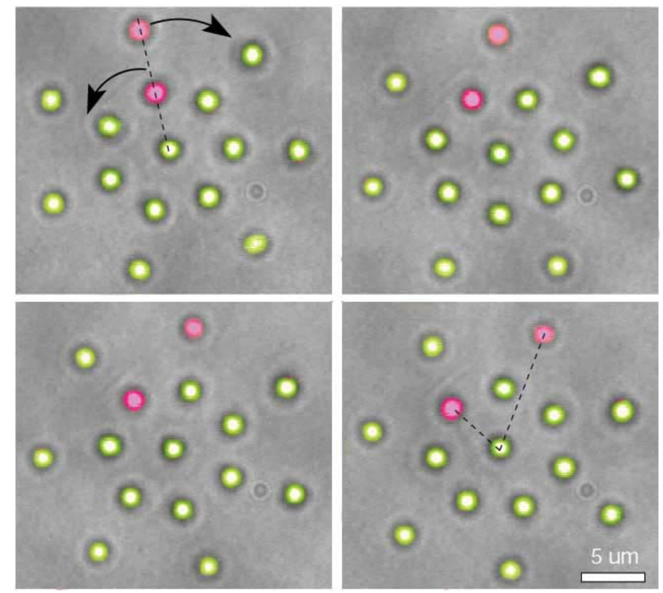
Holographic Optical Tweezers: Using light to manipulate small particles





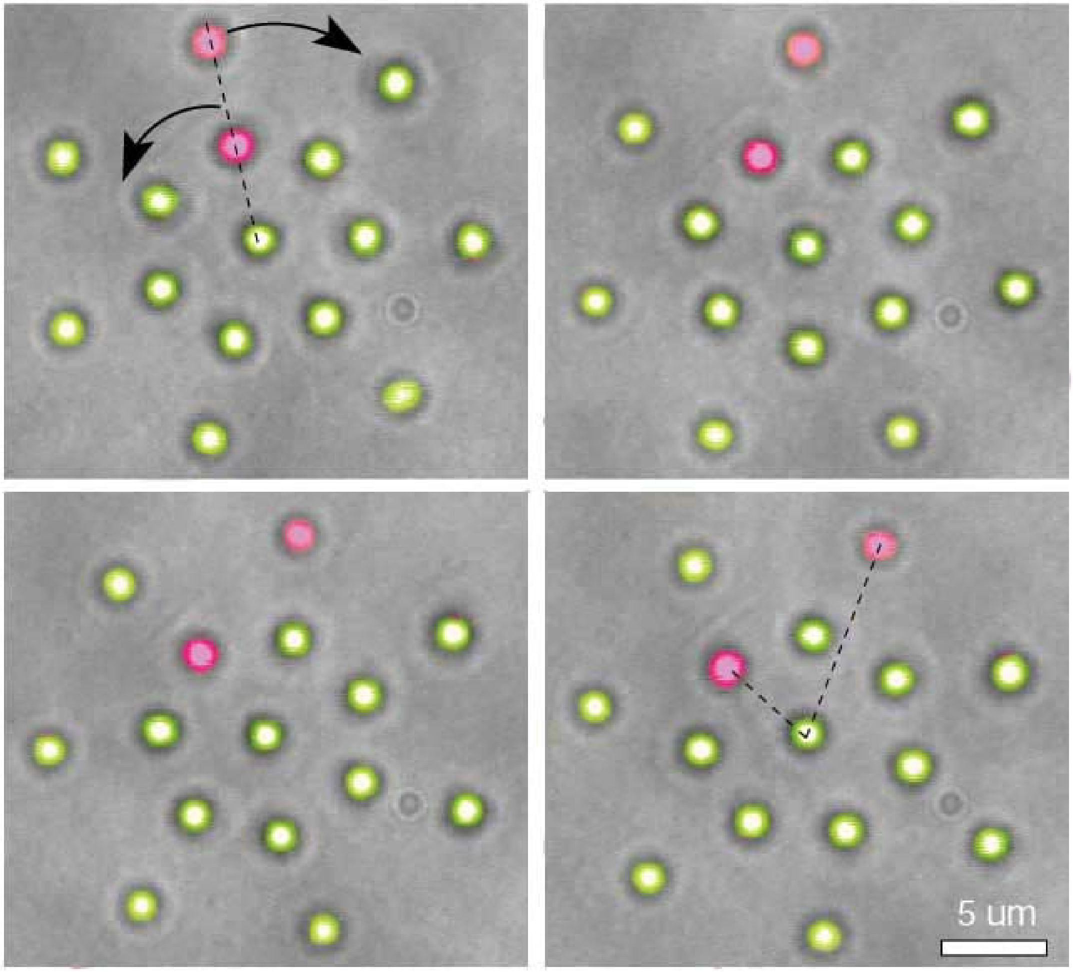
Manipulating objects at the mesoscopic scale (10^{-9} m to 10^{-4} m) is like trying to work without your hands. You can often see clearly but it is difficult to perform even the simplest of tasks.

A novel way to solve this problem is through optical trapping. A focused beam of light can act as a sort of "hand" to grab small particles. Optical traps are typically set in a large pool of freely moving particles to catch objects that happen to pass nearby. Once the object is trapped its position can be adjusted by moving the beam of light. Optical traps designed to move tiny objects are known as optical tweezers.

Light exerts a few piconewtons (10^{-12} N) of force on any object capable of supporting an electric field that absorbs, reflects, or refracts light. A piconewton is not much force but it is more than enough to move cells and other mesoscopic particles. If the light is focused through a lens this force pushes the object toward the focal point of the lens and traps it there as depicted in **Figure 1**.

Professor David Grier and his group here at the University of Chicago Materials Center have improved upon the design of basic optical tweezers with a method for manipulating mesoscopic particles called Holographic Optical Tweezers. The key to this method are the computer-generated holograms used as the Diffractive Optical Element (DOE) in **Figure 2**. These holograms use diffraction to split the input beam into over a thousand beams of light going in different directions that each create a separate optical trap after passing through the objective lens.

Holographic Optical Tweezers: Using light to manipulate small particles



With this technology, it is now possible to manipulate numerous objects using a single laser. Before the introduction of Grier's technique, one would have needed a separate laser and optics for each object.

Holographic optical tweezers can move the objects they catch in three dimensions such as in **Figure 3**. In this example, the inner circle of objects rotates counterclockwise while the outer circle rotates clockwise. Such control opens the door to a wide range of applications. Giving scientists hands to manipulate objects in the mesoscopic realm allows them to assemble heterogeneous chemical structures or perform surgery on living cells. These possibilities are being explored in collaboration with Arryx Inc, a company founded here in Chicago for the sole purpose of marketing Holographic Optical Tweezers technology.

Optical tweezer arrays and optical substrates created with diffractive optical elements E. R. Dufresne and D. G. Grier, *Rev. Sci. Instr.* **69** (1998) 1974.

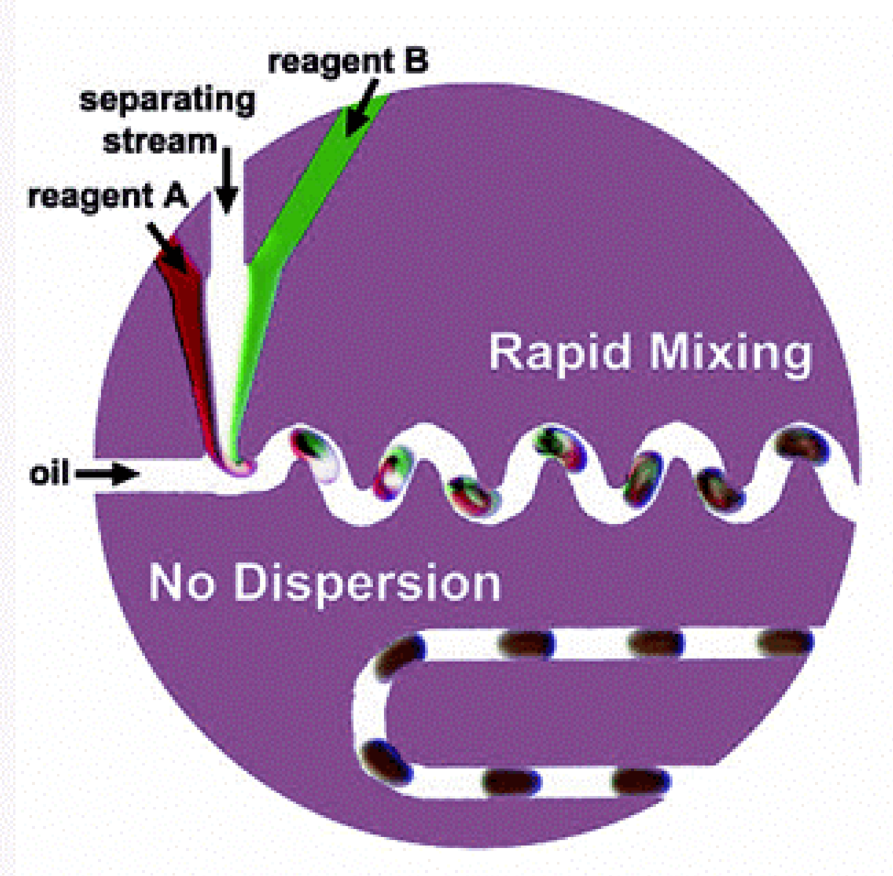
Apparatus for applying optical gradient forces
D. G. Grier and E. R. Dufresne, U.S. Patent 6,055,106 (2000).

Computer-generated holographic optical tweezer arrays
E . R. Dufresne, G. C. Spalding, M. T. Dearing, S. A. Sheets and D. G. Grier, *Rev. Sci. Instr.* **72** (2001) 1810

Chicago Materials Research Center / MRSEC

Heinrich M. Jaeger, University of Chicago, DMR-0213745

Microfluidics for Controlling Reaction Networks in Time



H. Song, J. D. Tice, **R. F. Ismagilov**,

Angew. Chem. Int. Ed. **42** (7), 767-772 (2003).

Effective mixing is crucial for microfluidic reactors, yet so far has been difficult to achieve. Recent advances at the Chicago MRSEC provide an elegant solution to the problem.

Rustem Ismagilov and his group (including MRSEC-supported undergraduate Josh Tice) have developed a simple pressure-driven microfluidic system that overcomes two problems of microfluidics: it transports solutions with rapid mixing and no dispersion. The researchers eliminated dispersion by localizing reagents within aqueous plugs separated by water-immiscible oil. Millisecond mixing of the reagents was achieved using chaotic advection. This system consumes samples at a ~10,000 times lower rate than devices that rely on turbulence for mixing.

Chicago Materials Research Center / MRSEC

Heinrich M. Jaeger, University of Chicago, DMR-0213745

Educational Outreach: Our Science Demo Team develops interactive hands-on demonstrations for museums, using MRSEC research as the starting point. The team consists of Center graduate students, who also perform the demonstrations at the Museum of Science & Industry (Chicago, IL), the Adler Planetarium (Chicago, IL) and the SciTech Hands-On Museum (Aurora, IL). The Science Demo Team reaches museum visitors of all ages and is a highly successful component of our Center's wide-ranging outreach program.

Effect of temperature on the rate of fluorescence in green and orange glow sticks.

Total internal reflection in a Plexiglass tank with water. The phenomenon also occurs in a flowing stream, when a tap located to the side is opened.

A Science Demo Team member (left) fielding questions by kids and parents.

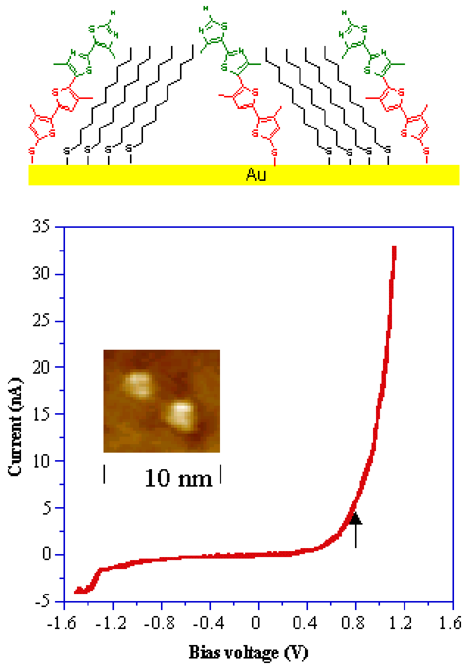
Chicago Materials Research Center / MRSEC

Heinrich M. Jaeger, University of Chicago, DMR-0213745

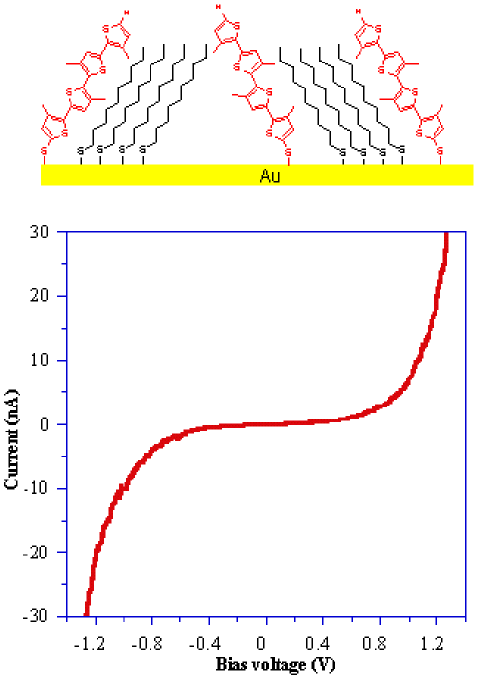
A New Building Block for Molecular Electronics

Researchers at the Chicago Materials Research Center, led by **Luping Yu**, have synthesized and demonstrated a new class of p-n junction molecules.

The molecules consist of diblock conjugated oligomers in which the two blocks have opposite electronic demand. The molecular structure exhibits a built-in electronic asymmetry, much like a semiconductor p–n junction. These rectifying molecular diodes provide an easy entry to molecular-scale electronic components for the design of logic circuits. Based on this work, a large number of structural and electronic property variations in this diblock system can be readily envisioned.



I-V **curve of new class of molecule working as rectifying molecular diode**



I-V **curve of control oligomer exhibiting no rectification**

Electrical measurements by scanning tunneling spectroscopy (STS) reveal pronounced rectification (left). Definitive proof for the molecular nature of the rectifying effect is provided by control experiments with a structurally similar reference compound that does not exhibit diode-like behavior (right).

Ng, Lee, and Yu, *J. Am. Chem. Soc.*, **124** (40), 11862-11863 (2002).

Chicago Materials Research Center / MRSEC

Heinrich M. Jaeger, University of Chicago, DMR-0213745

Educational Outreach: As part of the broad-ranging outreach program at our Center we offer internships to students from Chicago's *Young Womens' Leadership Charter School*, one of 12 all-girl public high schools in the United States. In the picture on the left, the P.I., Heinrich Jaeger, works in the lab with Yolanda, a 9th grade student at the YWLCS, on experiments involving granular convection and size separation.

> *"...there are many stages in the science field that we didn't know about but have learned about them during our internship. There aren't many women in the science field and because of that, that motivates us to pursue that as a career."*
>
> *Taneka, Veronica, & Elyse (10th graders at YWLCS)*

Taneka, Elyse, and Veronica (l-r) construct an electrical circuit using a lemon battery. Back at their school they will use this experiment to explain to others how circuits work..

Taneka & Elyse at work, developing a website about their internship.